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EVALUATION OF THE LARGE ARRAY LONG-PERIOD NETWORK

HARRY MACK
SEISMIC ARRAY ANALYSIS CENTER

DECEMBER 17, 1971

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A novel array processing technique is introduced which allows the detection and measurement of small amplitude Rayleigh waves.

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INTRODUCTION

One of our current tasks in the SAAC in Alexandria is to evaluate the capability of the network of the three large LP arrays, NORSAR, LASA and ALPA to detect and measure the amplitude of Rayleigh waves associated with P-wave detections reported in the LASA and NORSAR daily event summaries. There are two facets to this work. One is to perform the actual analyses and the other is to develop and implement suitable processing techniques so the data may be analyzed automatically within real-time.

The assumption is made that the SP detection threshold is inherently lower than the LP threshold. Hence, the SP bulletin is used to predict times at which Rayleigh waves, associated with each reported event, would be recorded by the three large arrays. All the LP data from the three arrays are stored in multiplexed form on a common tape; the SAAC low rate tape. Each tape contains approximately 12 hours of data. Software has been developed to access this tape directly, edit the individual channels and perform frequency-domain beamforming to detect and measure the power of Rayleigh waves. Time domain beamforming and plotting are available for visual display.

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CONTINUOUS ANALYSIS OF LASA LP DATA

One of the experiments performed was to analyze 50 days of LASA LP recordings using the LASA Daily Event Summary as a guide. To summarize the results the events were assigned to one of four azimuth ranges and one of two distance ranges. These are shown in Figure 1.

The ratios of detected to missed Rayleigh waves are shown in Figures 2a - 2h. The data have not been reworked to see whether or not more careful processing could bring out some of the missed events and so these results do not necessarily reflect true detection thresholds. Also only deep events reported by NOS have been left out but we must presume that many deep events, not reported by NOA, are included. Even with these restrictions there are some striking comparisons. Detection ratios for events from the south are poor when compared with those from the west and northwest. Detection ratios from the north are also lower than the west and northwest. Obviously deep events from South America and Asia are influencing these results but the difference is sufficient to suggest that comparisons would be similar if only shallow events were considered.

This continuous study also provided an estimate of how long a large event could render the array ineffective. The energy scattered from huge Rayleigh waves washes across the array from all directions for a period of hours and makes the detection of small surface waves impossible. After a magnitude 6.8 earthquake in Japan no events could be detected at LASA for a period of 4 hours. Also persistent coherent propagation was detected from an azimuth of around 70°.

ARRAY COMPARISONS

LASA-NORSAR

As part of the network evaluation, individual pairs of arrays are being compared by beaming them into an area which is equidistant from the two arrays in question. In the case of NORSAR and LASA a very convenient region is the Kurile Islands area. Both arrays are approximately 65° away from this seismic area. The structure of the travel paths is somewhat different. Rayleigh waves received at LASA travel through the north Pacific and the Aleutians area, then through western Canada, altogether a rather complex path. The path from the Kuriles to NORSAR may be considered a bit simpler as the bulk of the propagation occurs through the northern part of the Asian continent. Using Kurile islands events reported in the LASA Daily Event Summary the LP data from NORSAR and LASA was beamed and searched to detect and measure Rayleigh waves from these events. The seismic events used so far in this study were recorded in the period May-November of this year. No events were used previous to this period as the current format for data transmitted from NORSAR to the SAAC was established on May 1st.

Figure 3 shows the m_b - M_s plots for these data for both NORSAR and LASA. The events used were the same in both cases. There are more points visible on the LASA plot. This is because the NORSAR data transmitted by the TAL, contains gaps during the analysis period

and so some events analyzed for LASA were not available for NORSAR.

There is however, a good deal of similarity between the two distributions, with most of the events occupying the same relative positions in the two respective plots. Of the points that are common to the two, most exhibit a slightly higher M_s value at NORSAR than at LASA. The difference is typically 0.2 - 0.3 M_s but some larger differences can be seen. This may be an effect of the travel path difference mentioned before.

In Figure 4 the events have been broken down into magnitude groups with a view to establishing detection/non-detection ratios. The magnitudes are the body wave magnitudes reported in the LASA Daily Event Summary. Rayleigh waves from all events with $m_b > 5.0$ were detected, as would be expected. In the range $m_b = 4.5 - 4.9$, two events at LASA and three events at NORSAR were not detected by either array. In each case high amplitude waves from other events caused such strong interference that a detection of waves from the Kurile Islands could not be confidently picked.

The magnitude range m_b 4.0 - 4.4 is the range where we are currently expending the most effort and it can be seen that both arrays are quite good.

In the suite of events examined both NORSAR and LASA missed one event each of magnitude greater than 4.0. Both were of magnitude 4.1 and were different events. We have no way of deciding whether or not these events had marked radiation patterns. Also we do not know whether or not the

events classified as missed due to interference would in fact have been detected had the interfering signal not been present. It must be remembered that our data source is the LASA Daily Event Summary which we must presume is not complete especially at m_b = 4.0-4.1. Hence even though detections were made for all events in the data set used it cannot be claimed that we are detecting surface waves from all events with $m_b \geq 4.0$. However we are encouraged by the results so far.

Although we have not analyzed many events at magnitudes lower than m_b = 4.0, a few have been included here to show that surface wave detections from such small events do occur. More will be added as the work continues.

It would appear that there is no major difference between NORSAR and LASA in the detection of Rayleigh waves from the Kurile Islands, at least for events with body wave magnitudes greater than 4.0.

ALPA-NORSAR

ALPA and NORSAR have special interest because they are closest to the Sino-Soviet region and the ray paths from a particular event to each array are approximately orthogonal.

Unfortunately there is no highly seismic region equidistant from ALPA and NORSAR as the Kuriles served LASA-NORSAR, but if the central Asian area as a whole is considered then useful comparisons can be made.

Due to the poor quality of the LP data from both

arrays until just recently, only events recorded since September have been considered. m_b - M_s plots for events commonly recorded at both arrays are shown in Figure 5. The distributions are similar but there is no indication of a systematic difference between the two sets.

Many events were detected at one array and not the other. Over one third fell into this category because of no data or bad data at one of the two arrays. This situation is improving.

A few are detected at one array only because of interference at the others. Figure 6 shows an M_s - m_b plot for all central Asian events recorded by one array or the other, or both.

NORSAR has the capability of detecting small events in the western and southwestern Soviet Union which cannot be detected by ALPA or LASA. So far we only have a small collection and an M_s - m_b plot is shown in Figure 7. Actually one of these points situated at M_s = 2.95, m_b = 4.9 was not well recorded at NORSAR due to coherent noise coming from the same azimuth. Figure 8 shows the NORSAR beam for this event. The noise is rather obvious and has been observed on several other occasions.

Figure 9 gives a composite M_s - m_b for the central Asia-west Soviet Union region as seen by ALPA-NORSAR and a little help from LASA. Some presumed explosions recorded by LASA before August have been added. These data are continuously being added to and reviewed as better processing techniques become available. With refined processing we consistently detect surface waves associated with events of $m_b > 4.0$ from Central Asia and the western part of the Soviet Union. Again it must be cautioned that our data set is small so far and cannot be considered complete and so we cannot as yet establish a network threshold for these regions.

SIGNAL PROCESSING DEVELOPMENTS

The design of our processing techniques is influenced by the volume of data to be processed. A fast frequency domain beamforming approach has been developed and utilized and operates at approximately 3 - 4 times real-time on continuous data. The output is a continuous listing of coherent detections with velocity, azimuth, signal power and signal-to-noise ratio. A wavenumber filtering scheme is included whereby a small signal can be detected in the presence of a much larger signal. An example is given in Figures 1a and 10b. Figure 10a shows the wavenumber plane for ALPA at a period of 19.0 seconds with two signals imposed. One is from the southwest and the other, with only 0.01 the power of the first, is from the northeast. The smaller signal is not at all visible. In fact time domain beamforming for the second small signal would give a spurious output of 8X the actual signal power. In Figure 10b the filter has been used and the data renormalized. The second signal is now dominant, the signal power estimate being 90 per cent of the true value. This type of processing allows us to detect and measure the power of small Rayleigh waves.

One other study in progress is the comparison of the spatial coherence of Rayleigh waves recorded at the three arrays. This study provides a quantitative comparison of signal deterioration across each array. Two examples are shown. The first in Figure 11 is for an event from Baja California recorded at LASA. The

spatial coherence is estimated in two orthogonal directions. It can be shown that the loss in coherence in the direction of propagation is caused by a variation in phase velocity at the period used and the loss of coherence along the mean wavefront is caused entirely by azimuthal scattering. The data can be explained by an angular scatter of $\pm$ 6° and a velocity scatter of $\pm$ 0.1 km/sec. A good example for NORSAR is a Turkish event and the spatial coherence estimates are shown in Figure 12. An angular scatter of $\pm$ 10° and a velocity scatter of $\pm$ 0.2 km/sec would explain these data.

Such studies as these have direct application in array processing as they indicate what type of weighting procedures should be incorporated to improve signal-to-noise ratios. There is also an interesting scientific content as the scattering affects the spectrum of a signal recorded at a single point and the fact that the phase velocity cannot be measured uniquely for a particular period would impose restrictions on structural models obtained by phase velocity inversion.

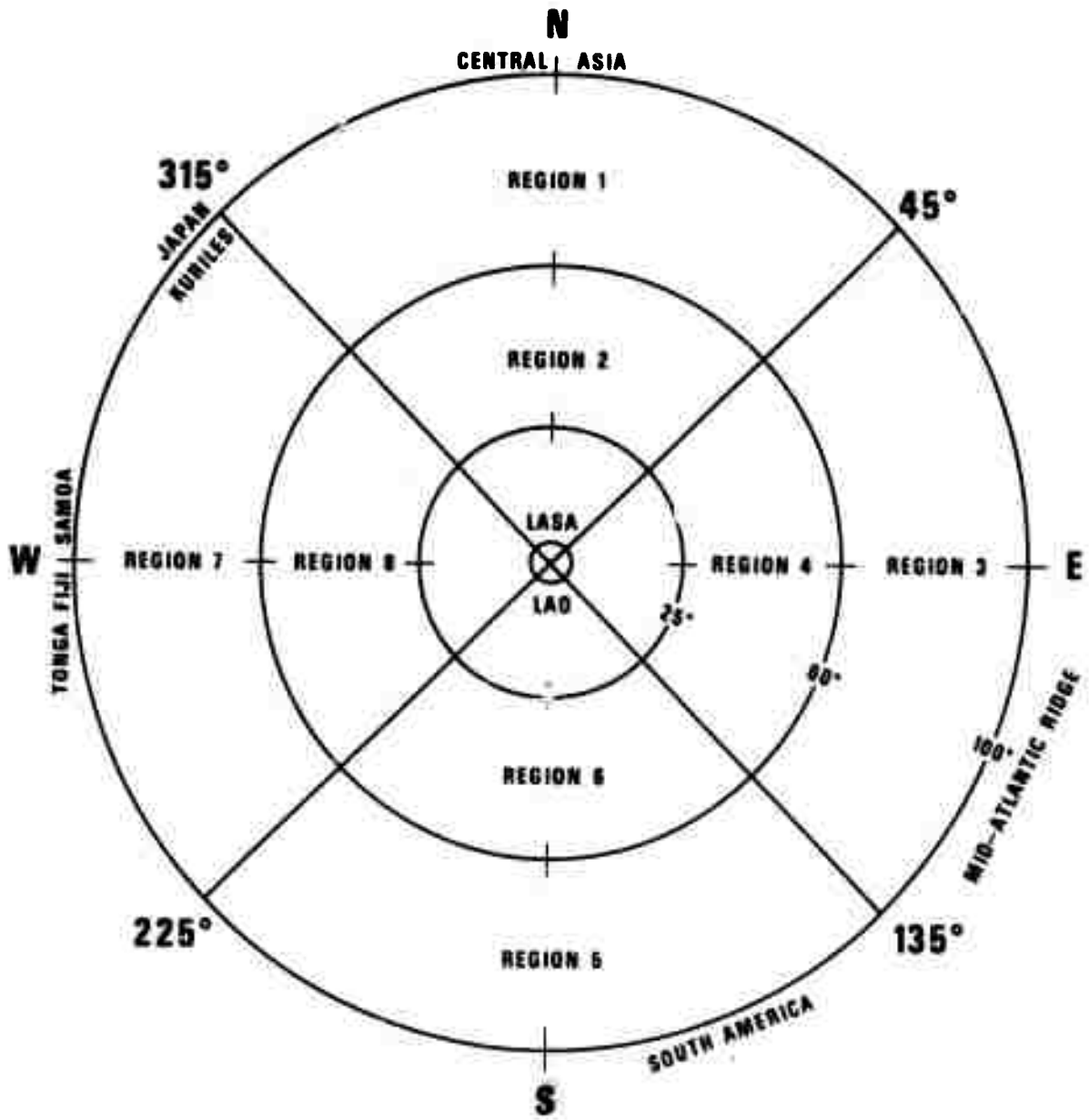


Figure 1. Location of regions used in LASA continuous analysis.

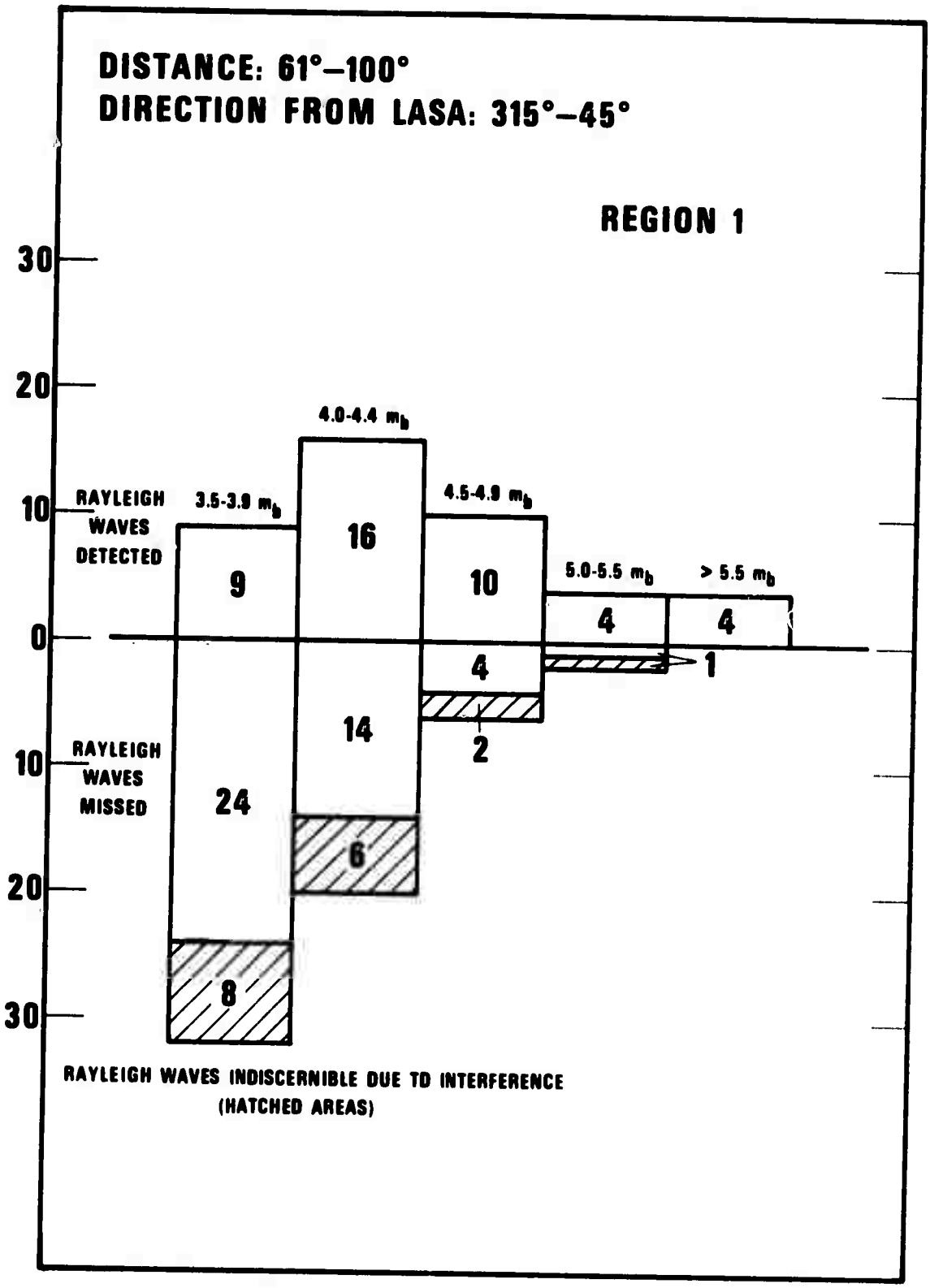


Figure 2a. Rayleigh wave detections/non-detections for region 1.

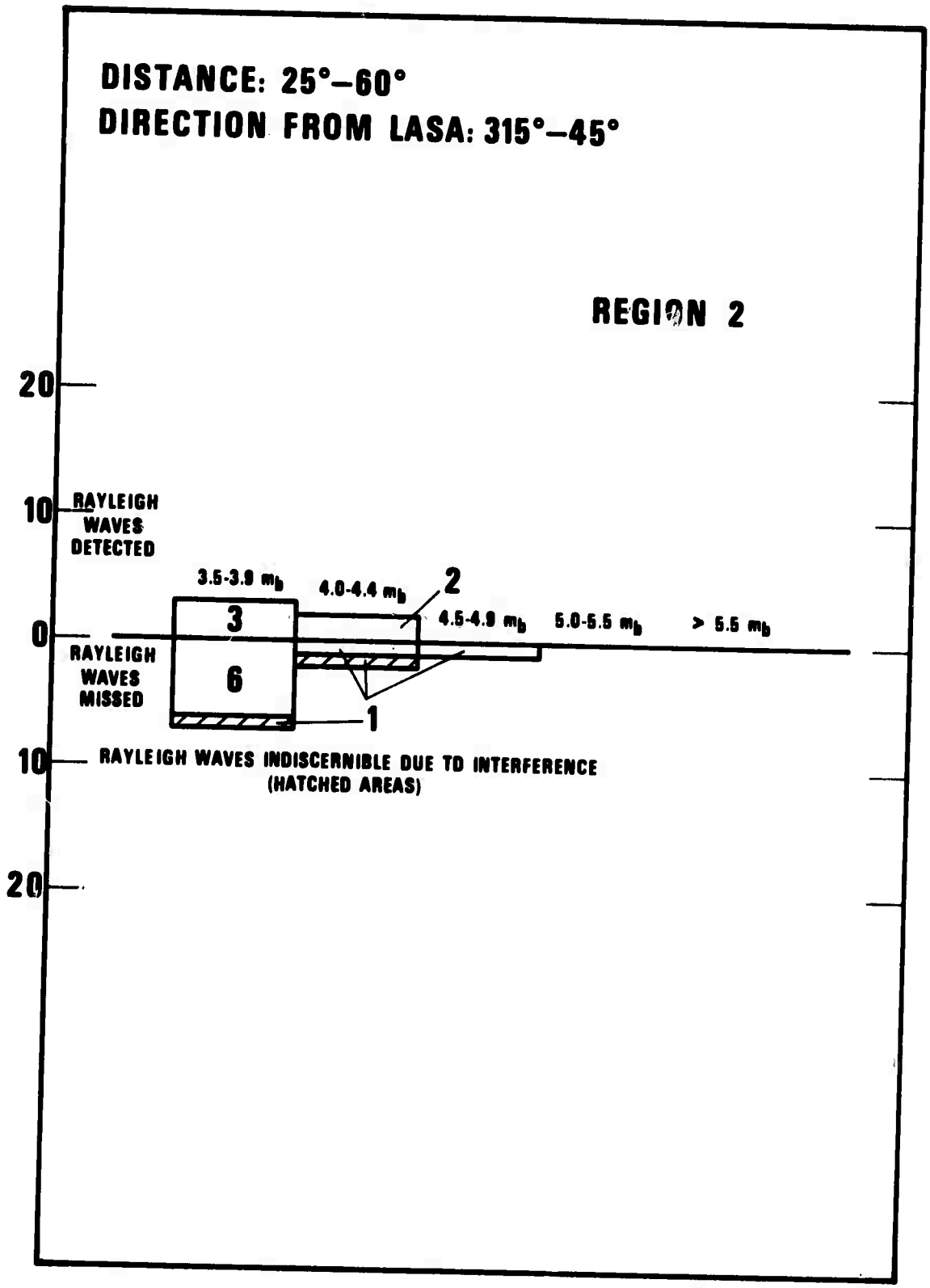


Figure 2b. Rayleigh wave detections/non-detections for region 2.

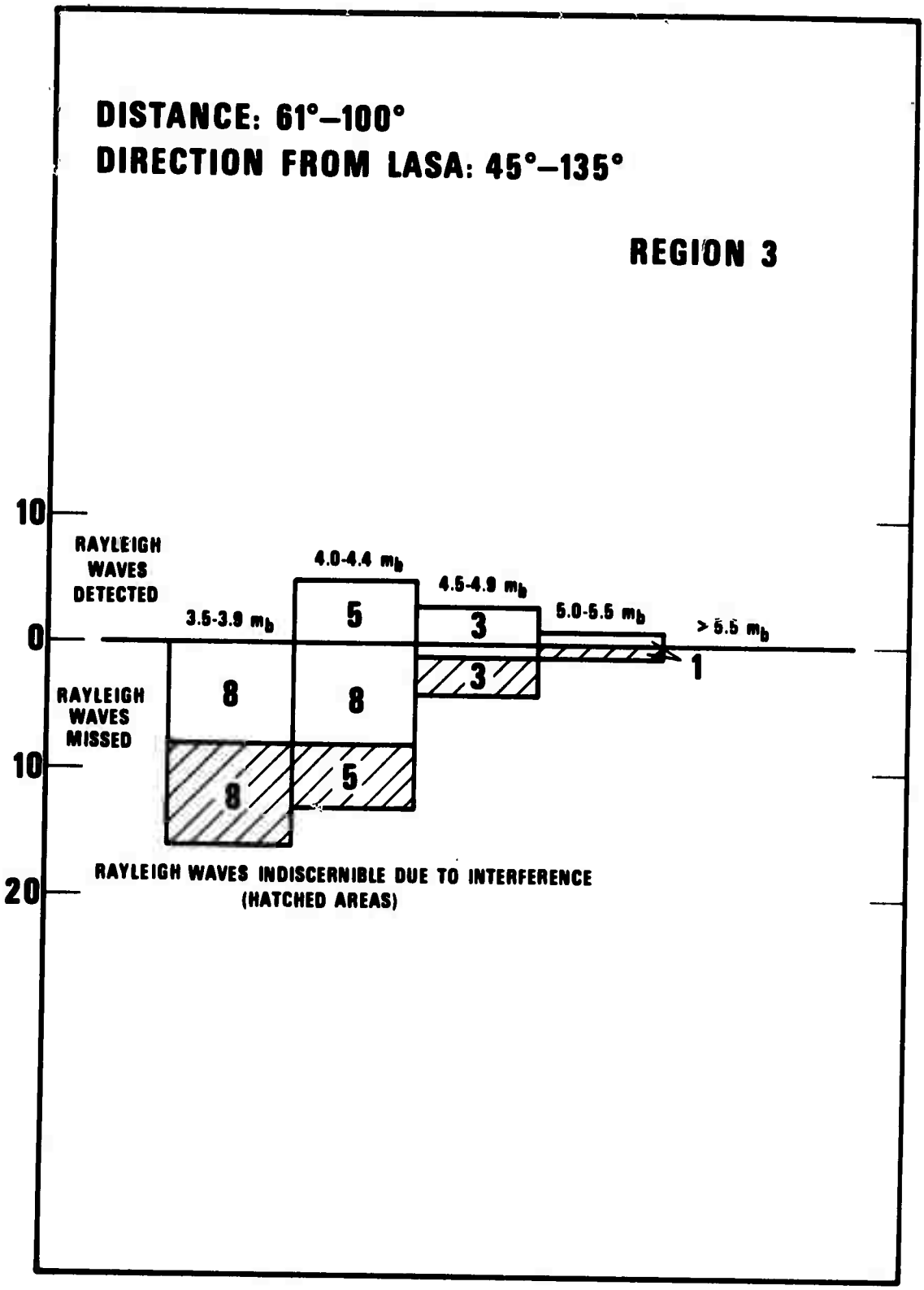


Figure 2c. Rayleigh wave detections/non-detections for region 3.

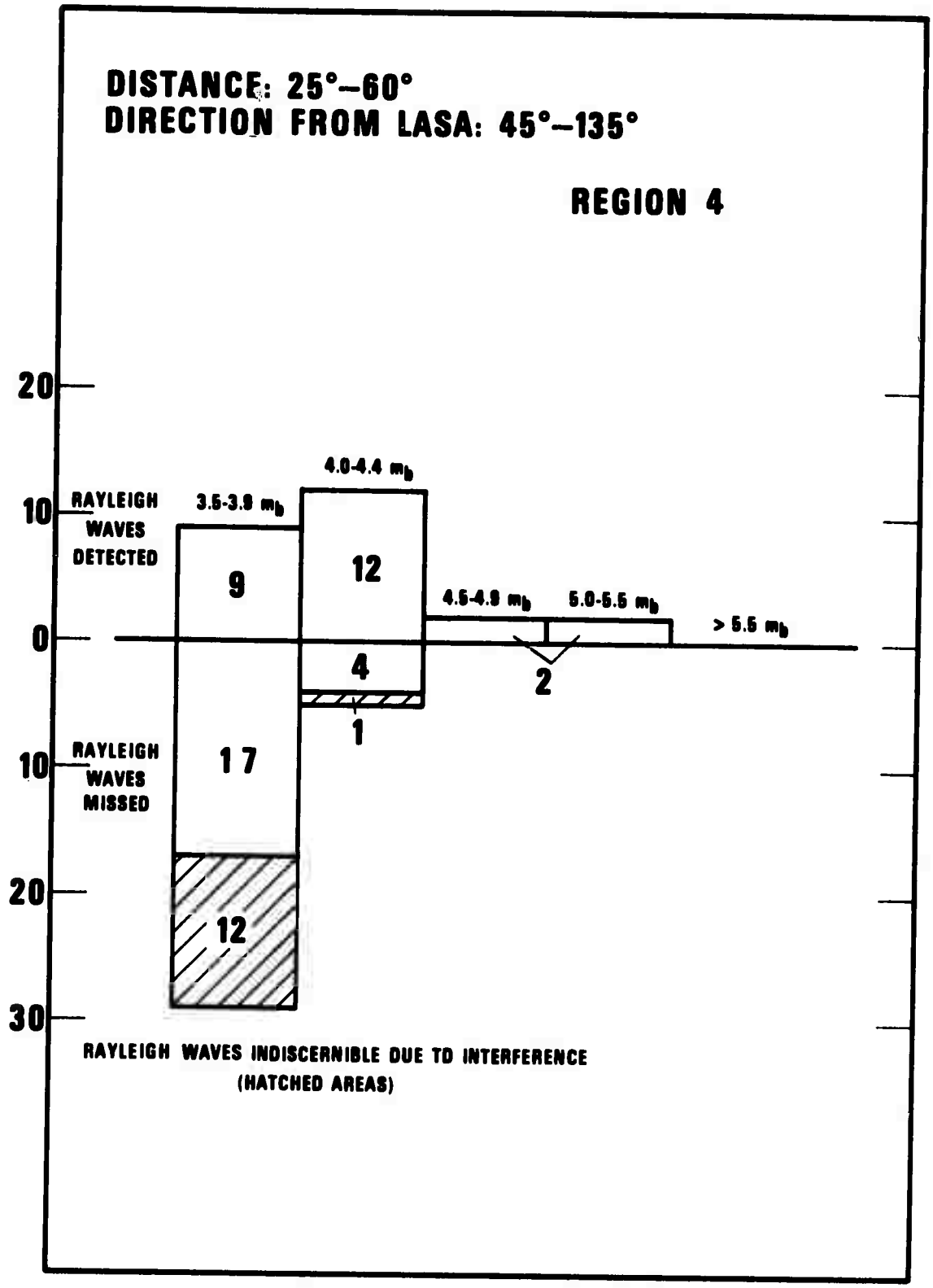


Figure 2d. Rayleigh wave detections/non-detections for region 4.

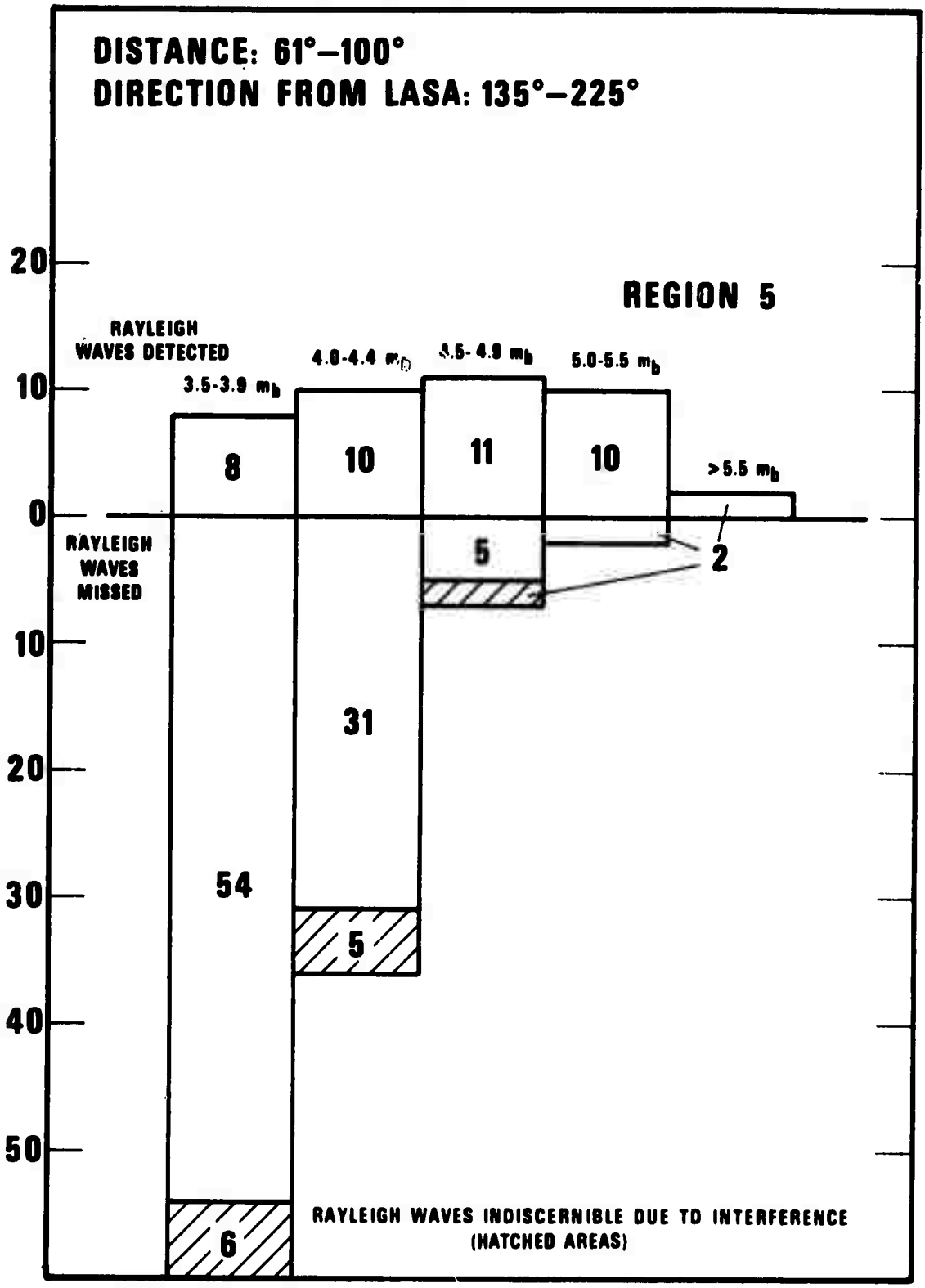


Figure 2e. Rayleigh wave detections/non-detections for region 5.

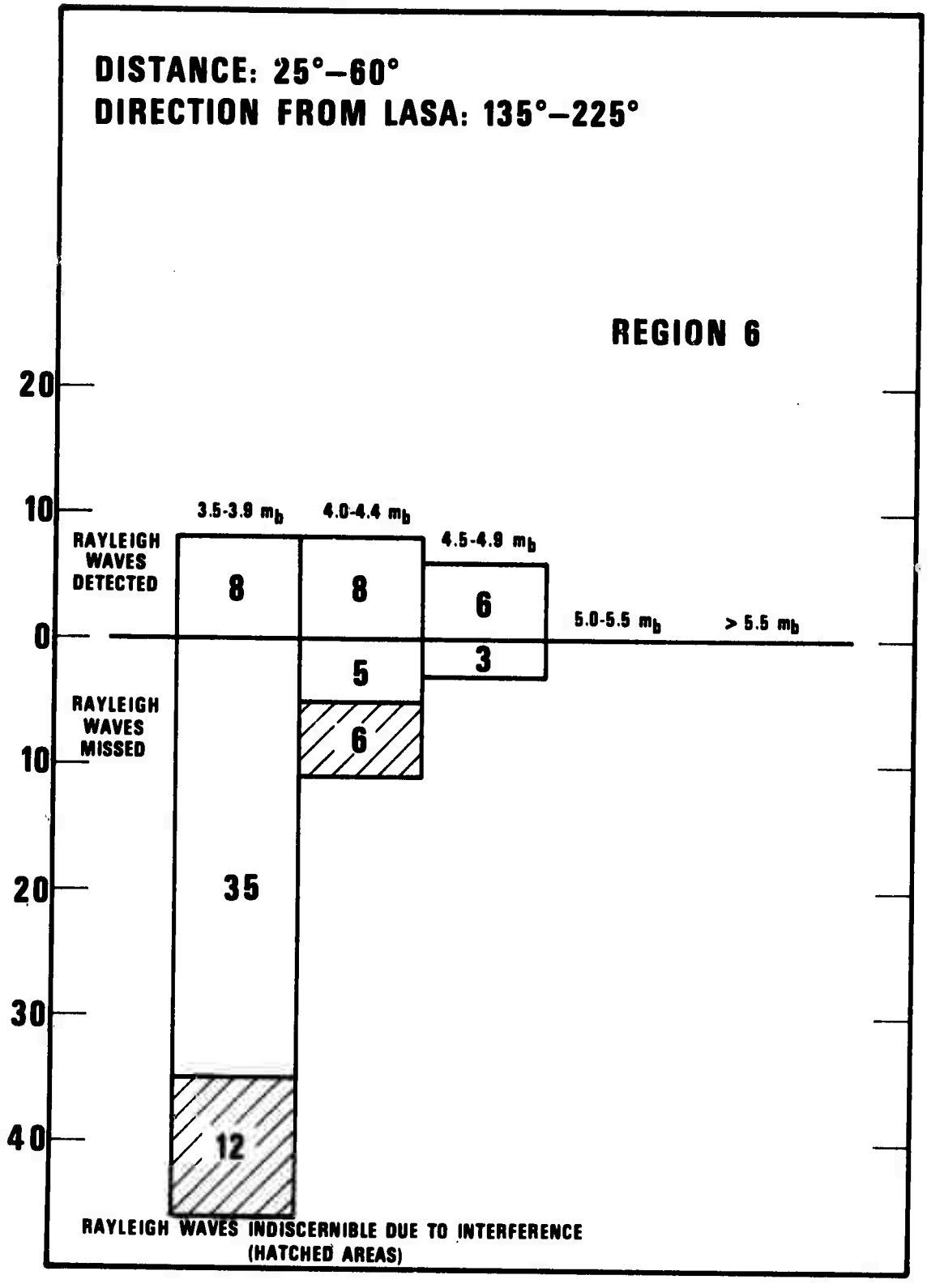


Figure 2f. Rayleigh wave detections/non-detections for region 6.

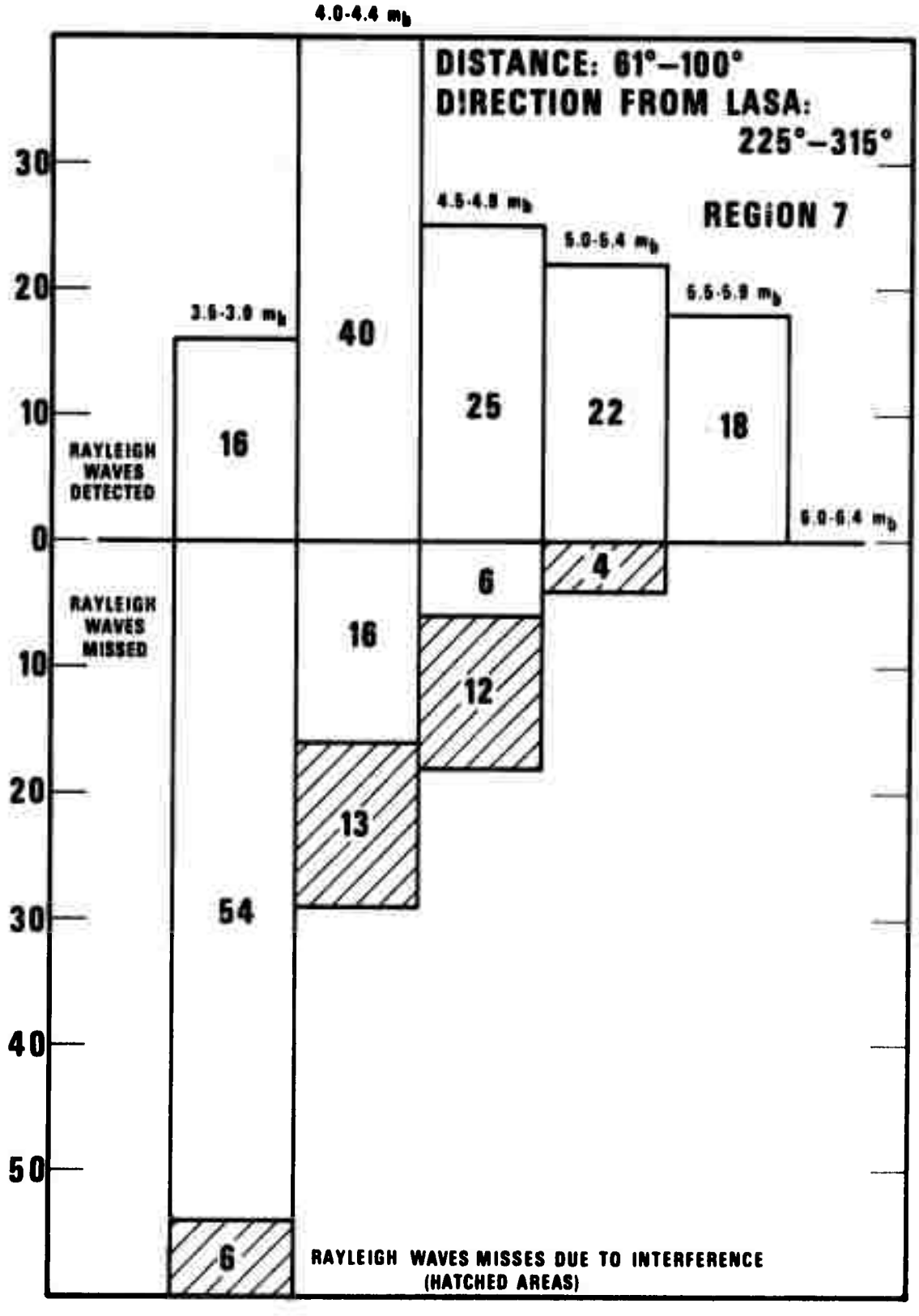


Figure 2g. Rayleigh wave detections/non-detections for region 7.

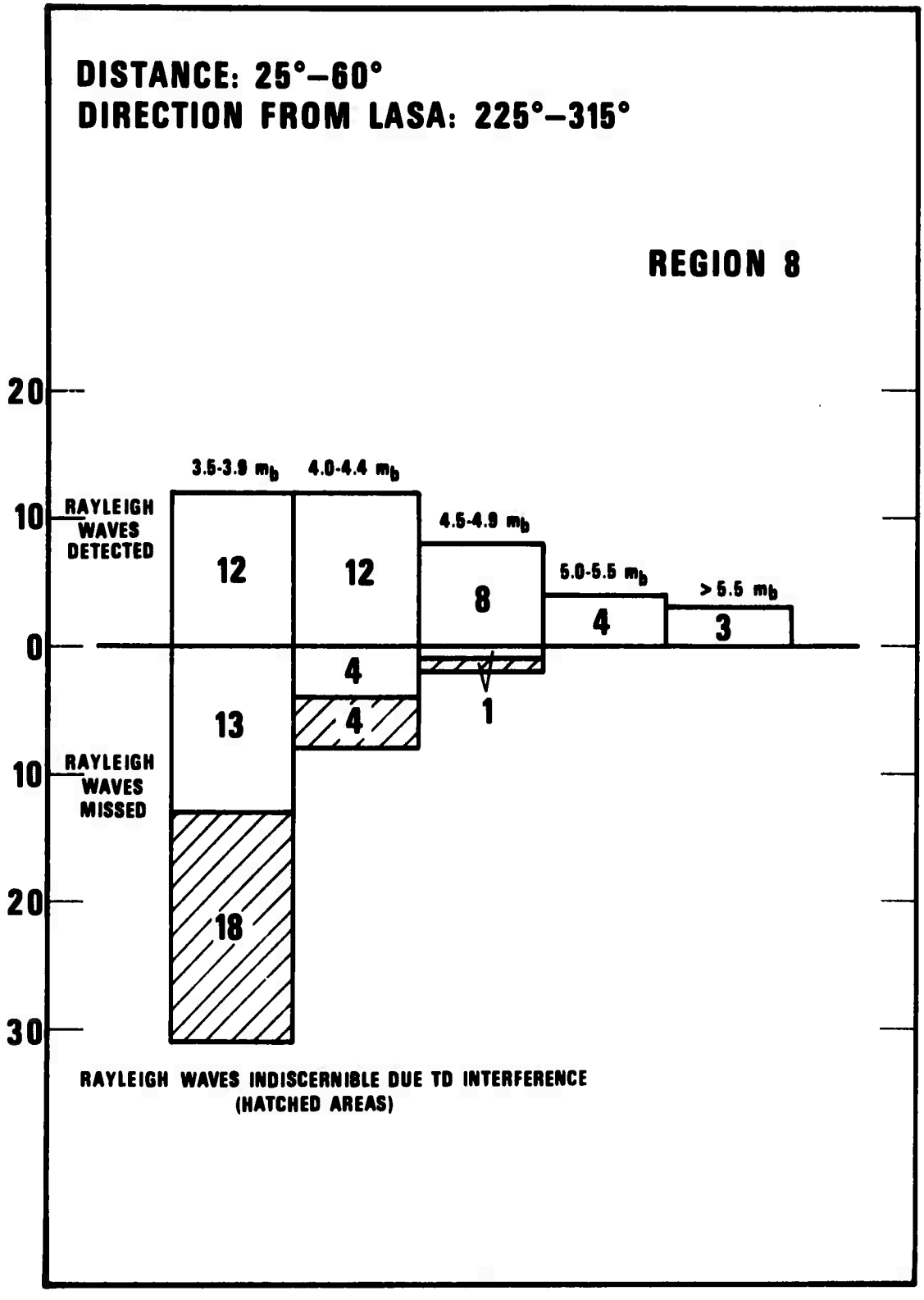


Figure 2h. Rayleigh wave detections/non-detections for region 8.

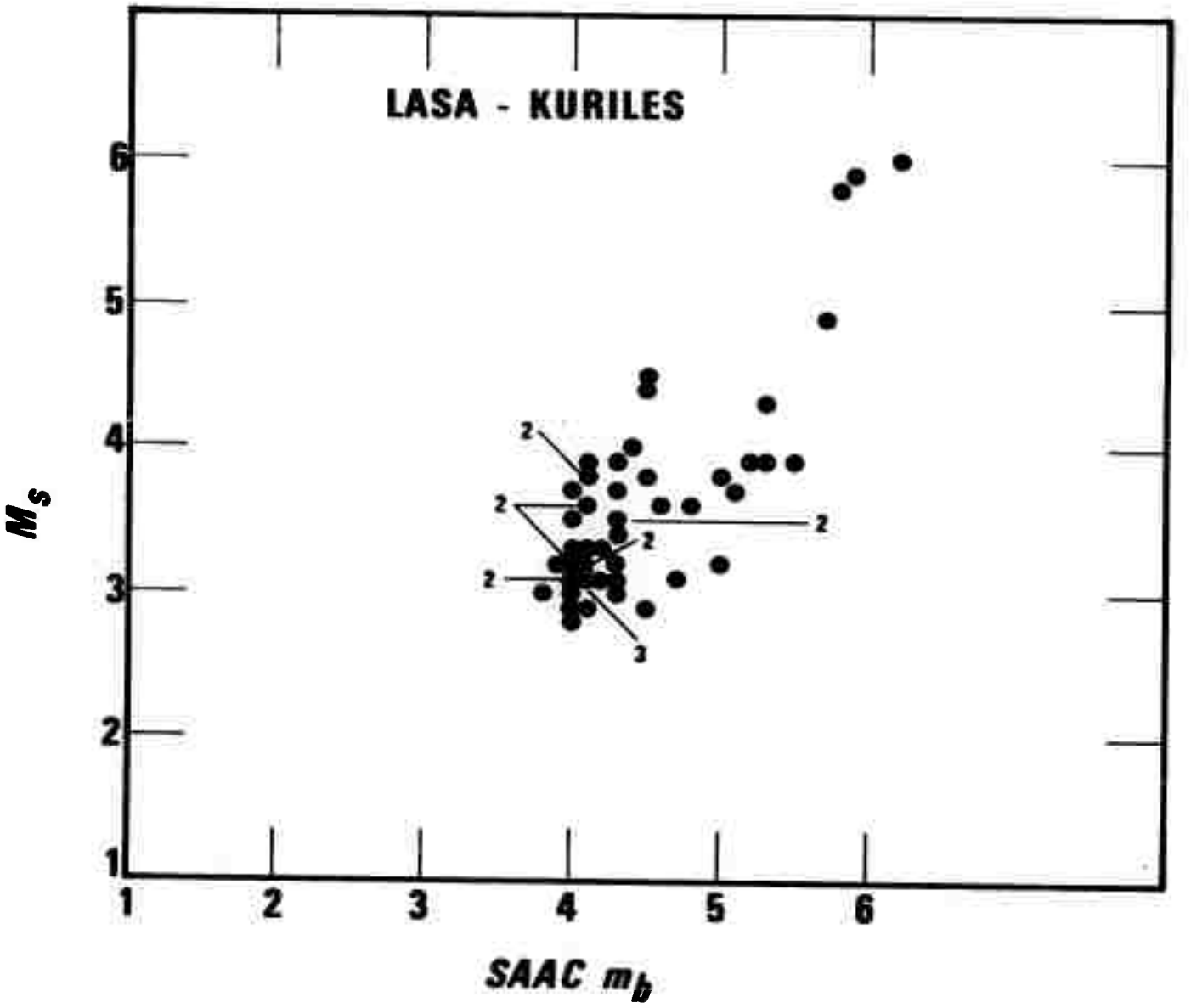


Figure 3a. SAAC m_b/M_s for suite of Kurile events recorded at LASA.

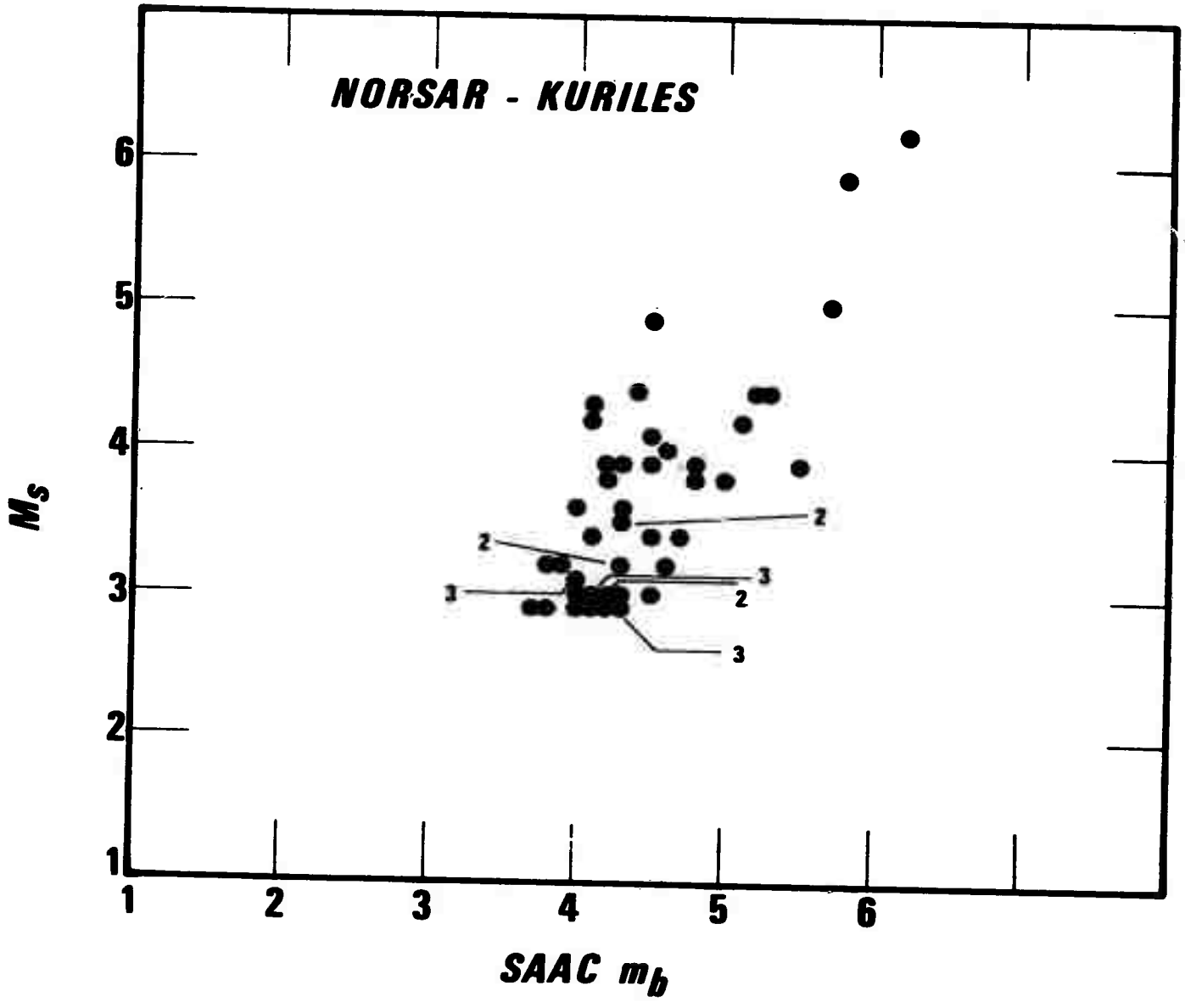
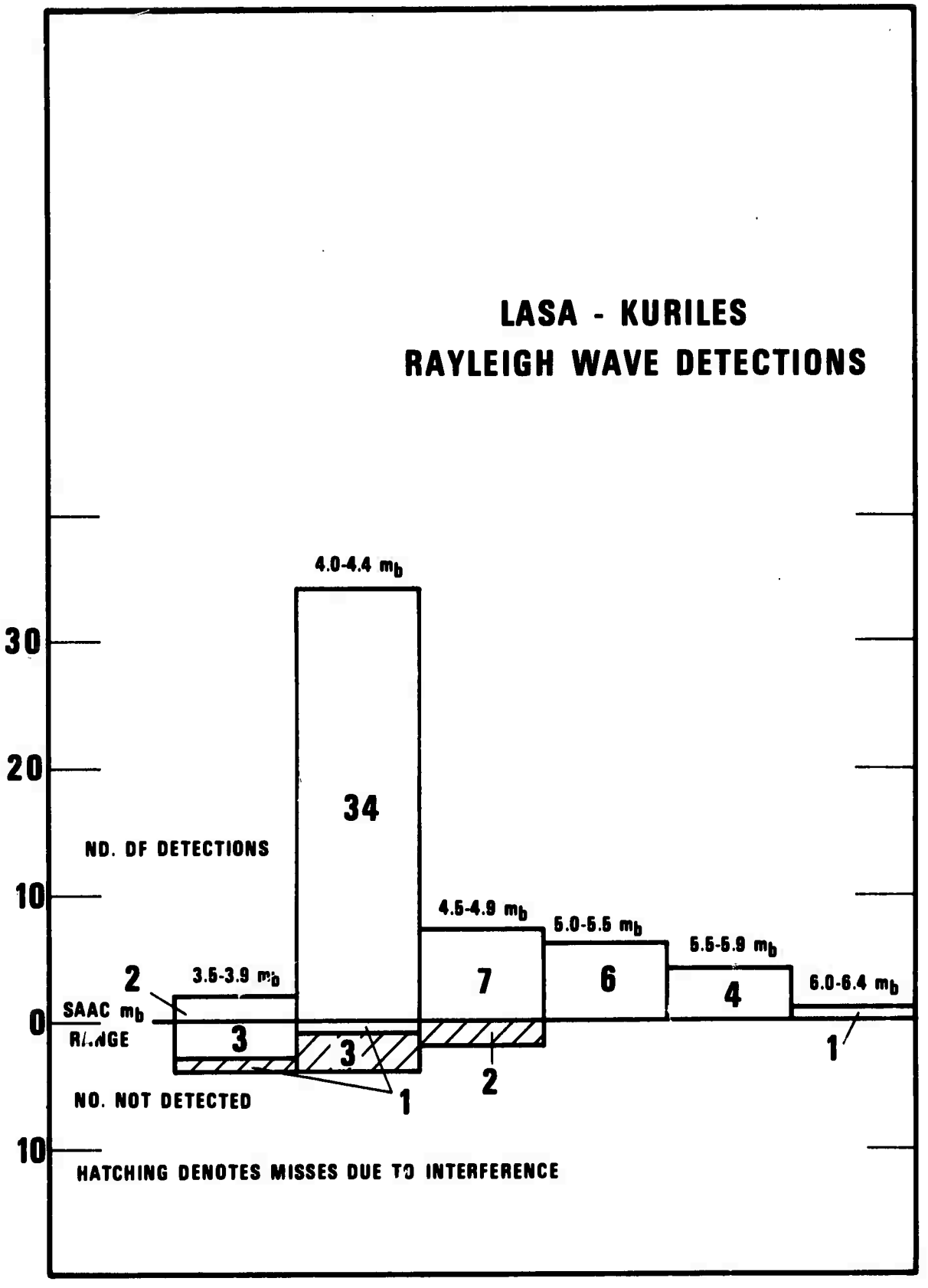


Figure 3b. SAAC m_b/M_s for suite of Kurile events recorded at NORSAR.



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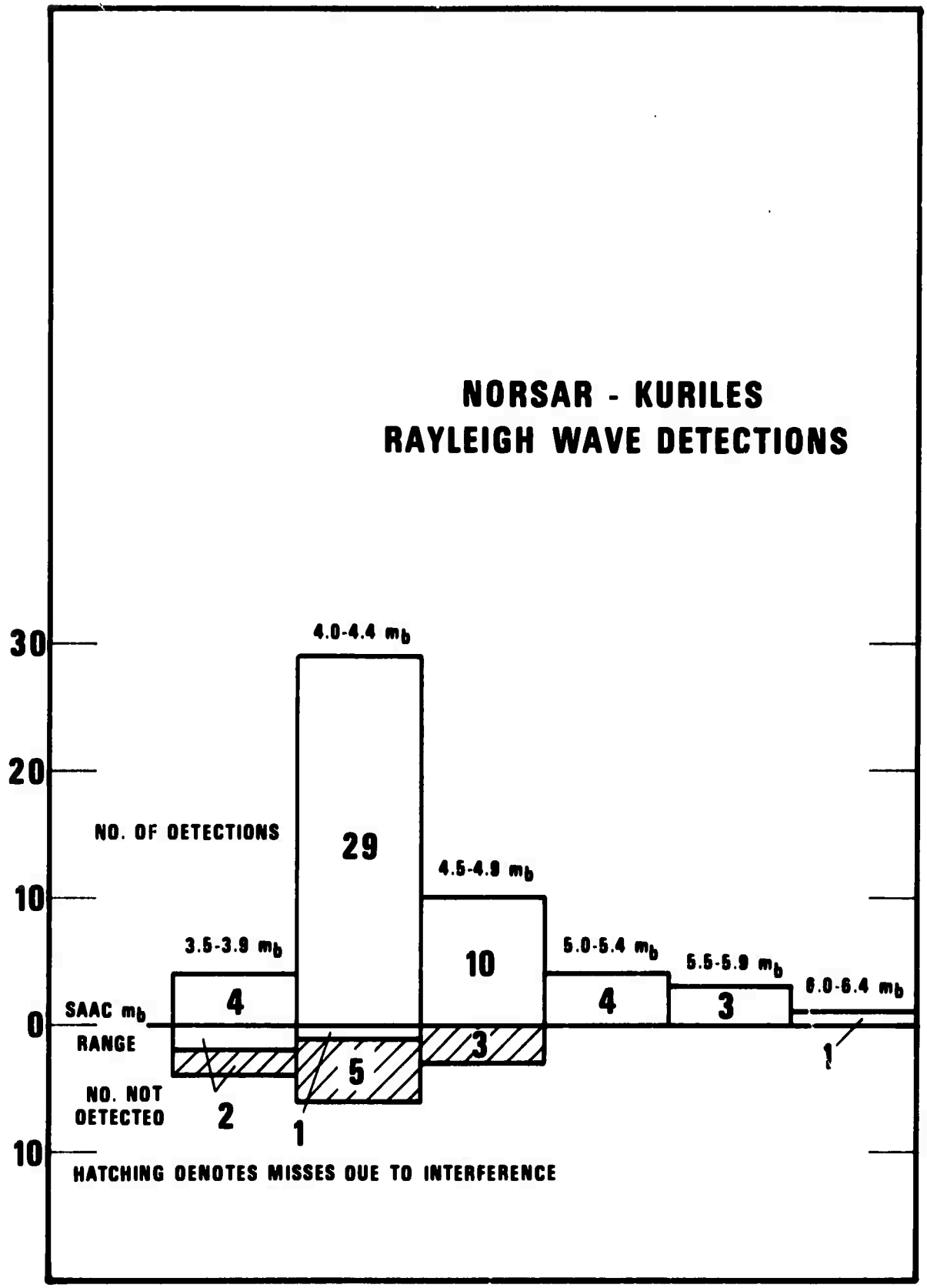


Figure 4b. Rayleigh wave detections and non-detections for Kurile suite at NORSAR.

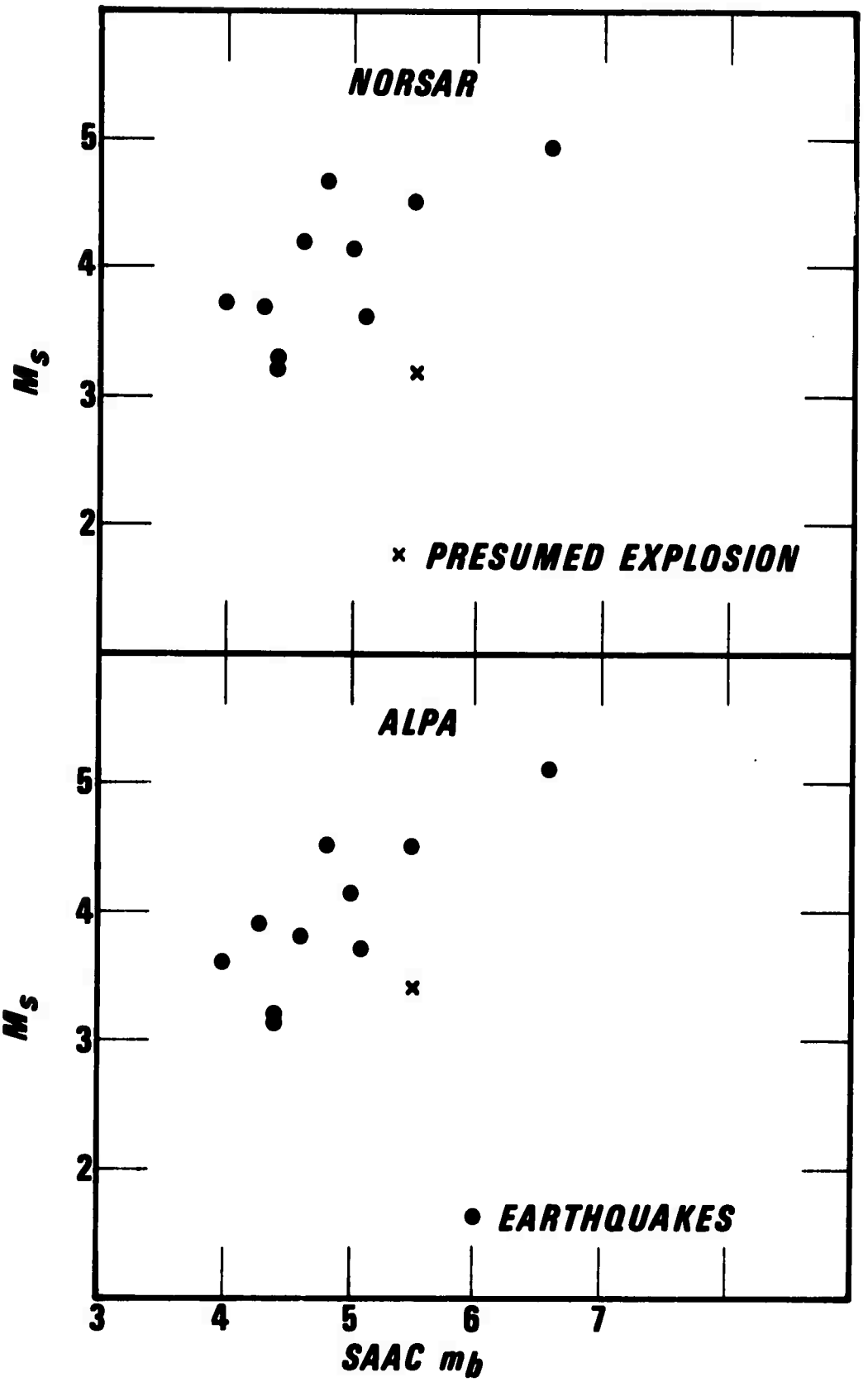


Figure 5. M_s - m_b plot for central Asian events recorded at both ALPA and NORSAR September - November 1971.

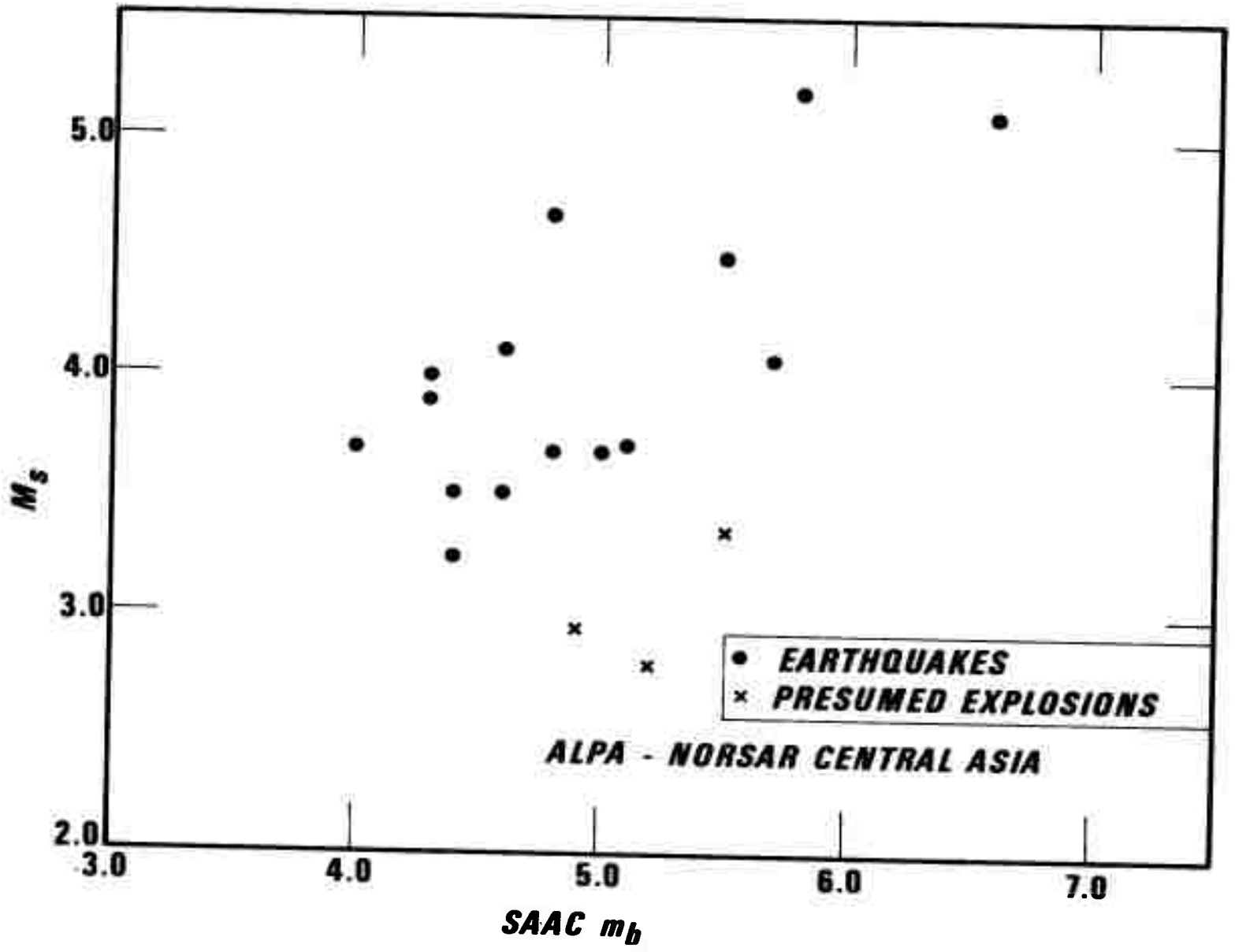
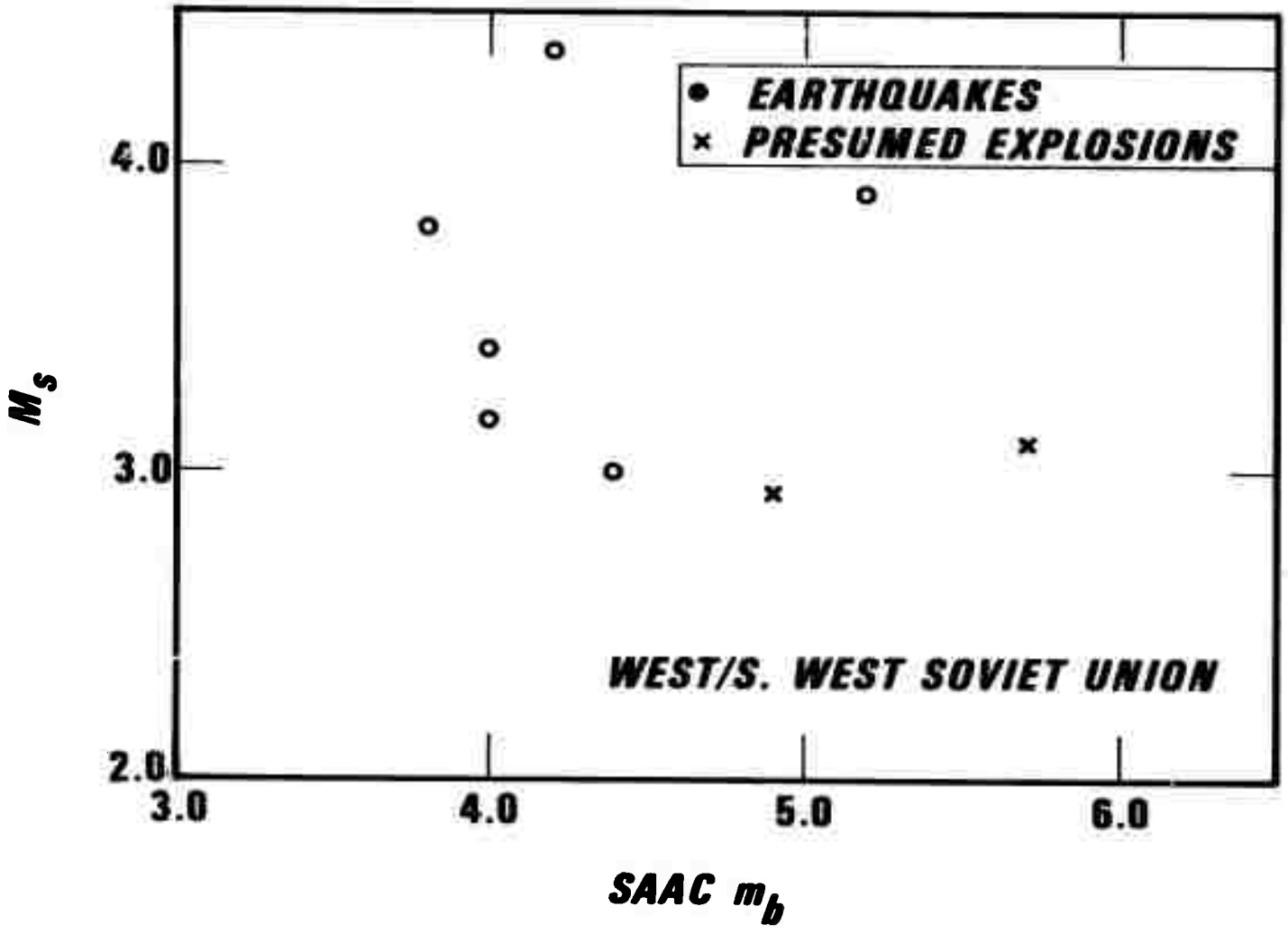


Figure 6. M_S - m_b plot for central Asian events recorded at ALPA and/or NORSAR September - November 1971.



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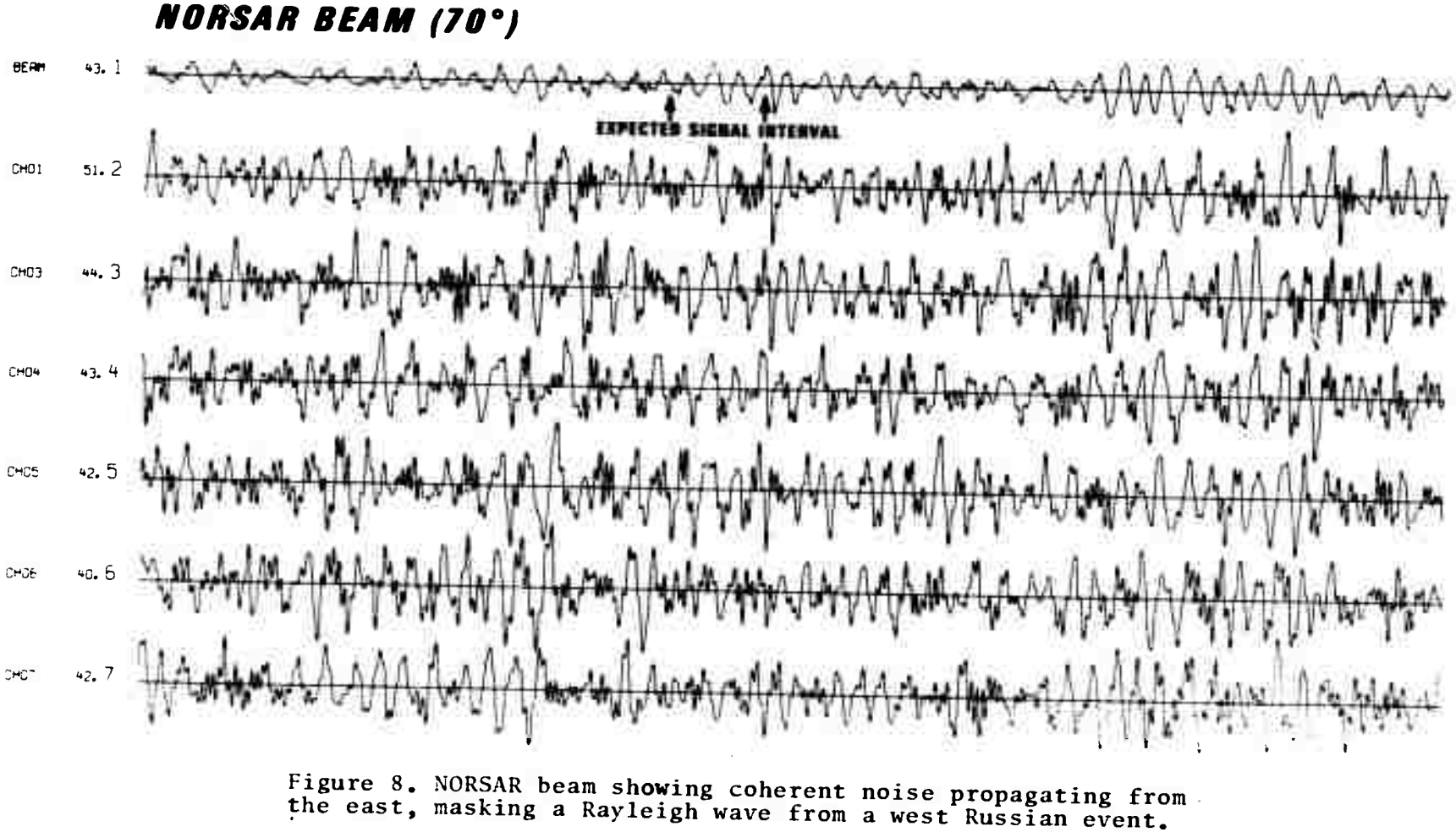

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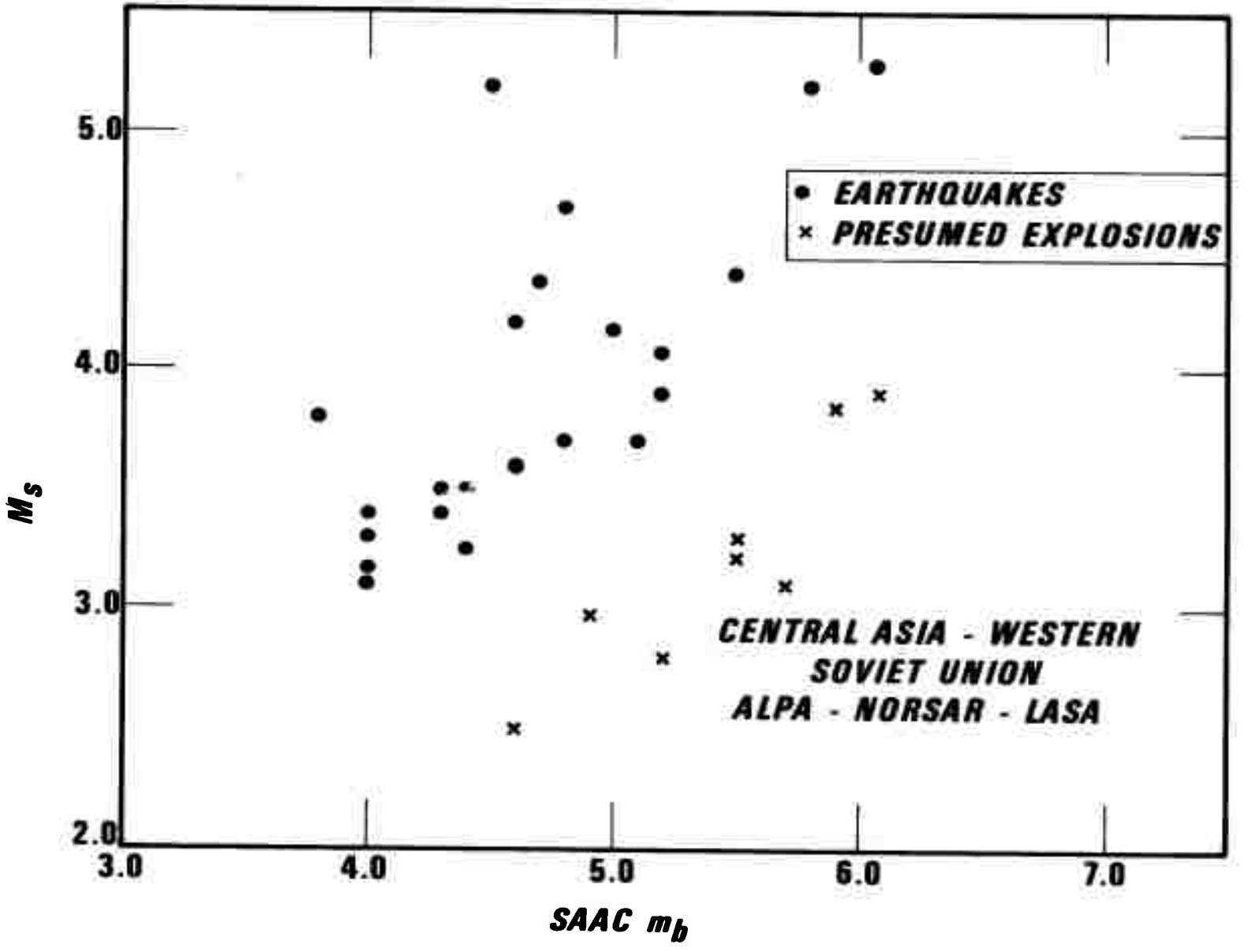

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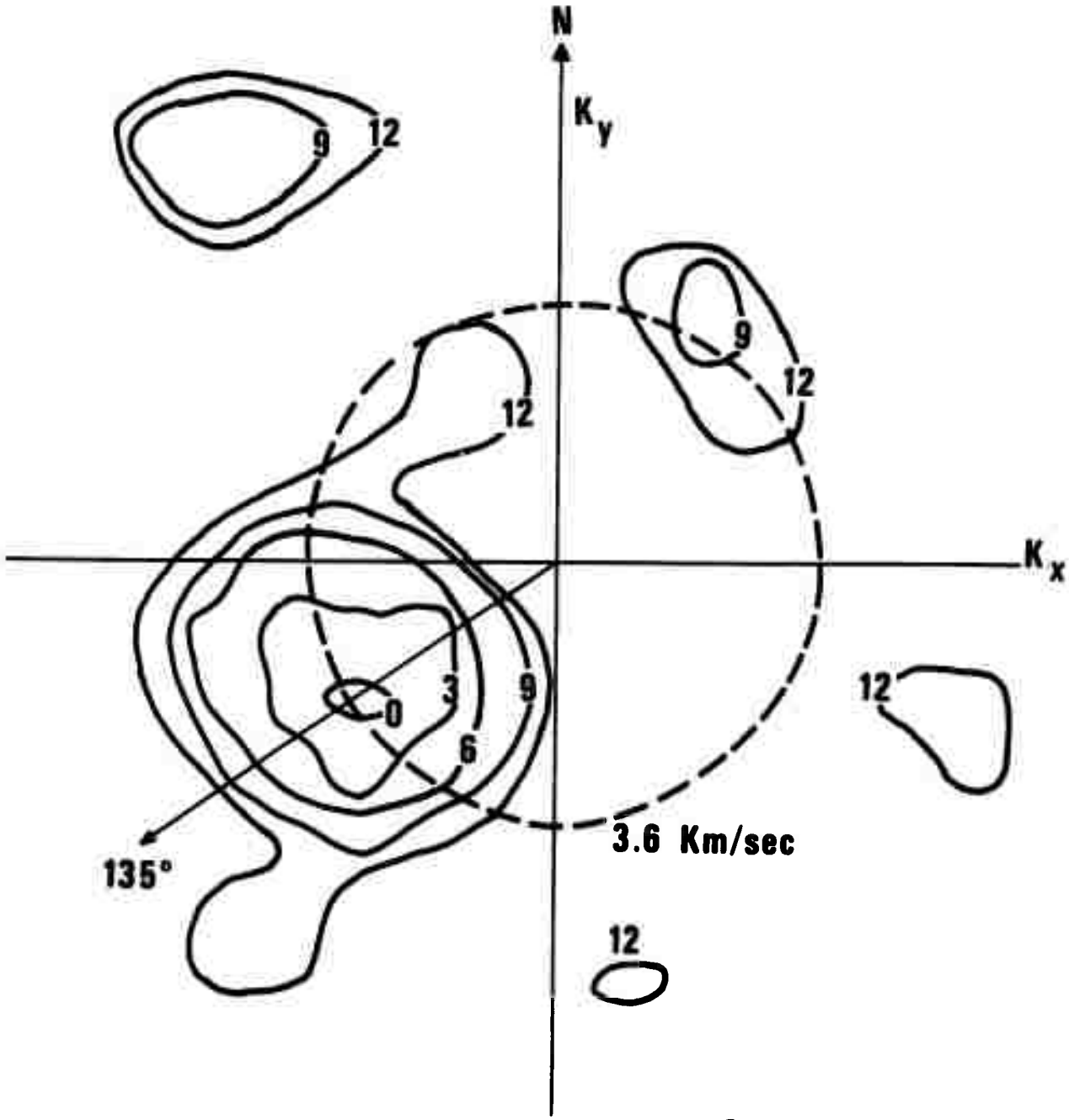

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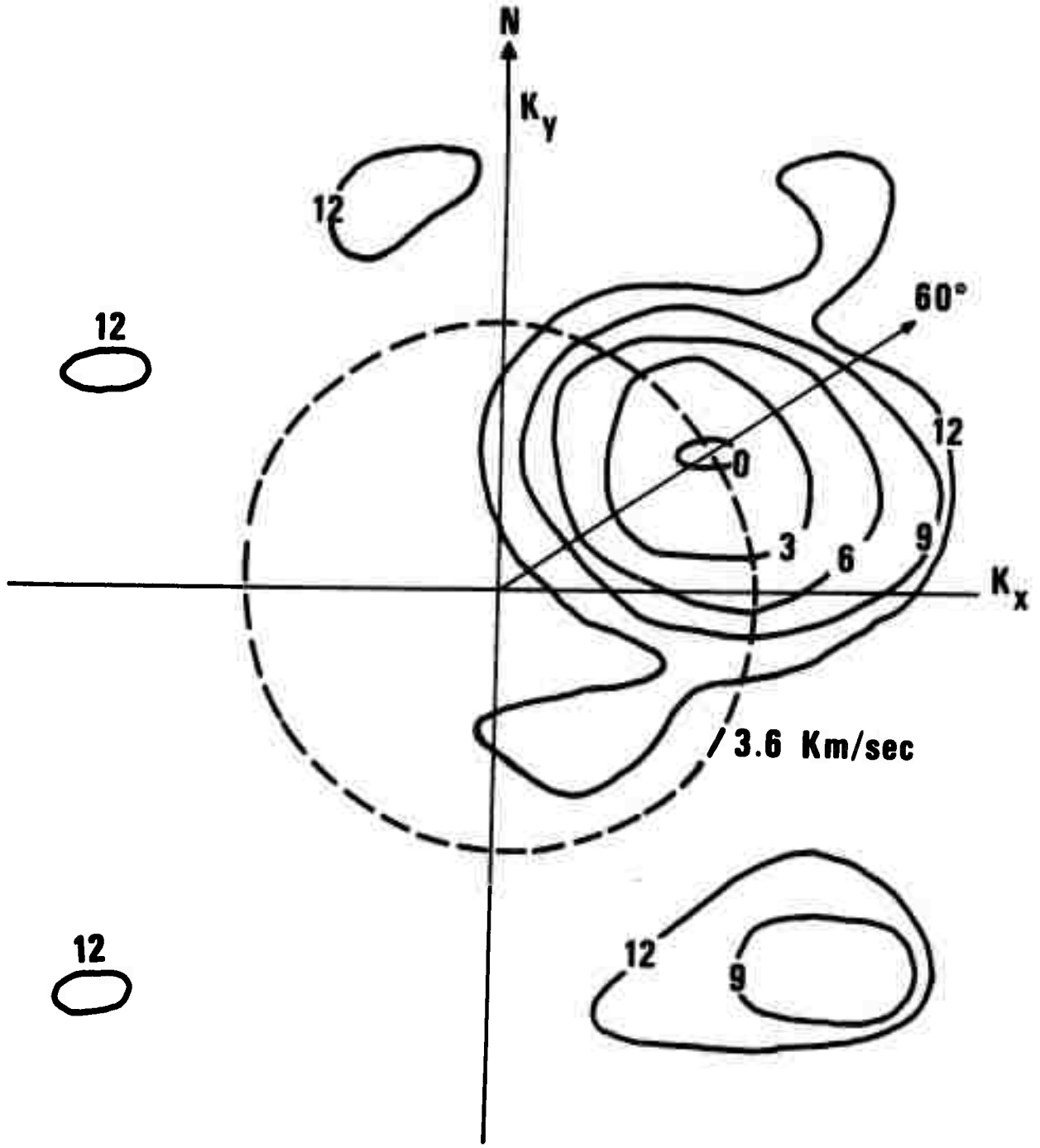

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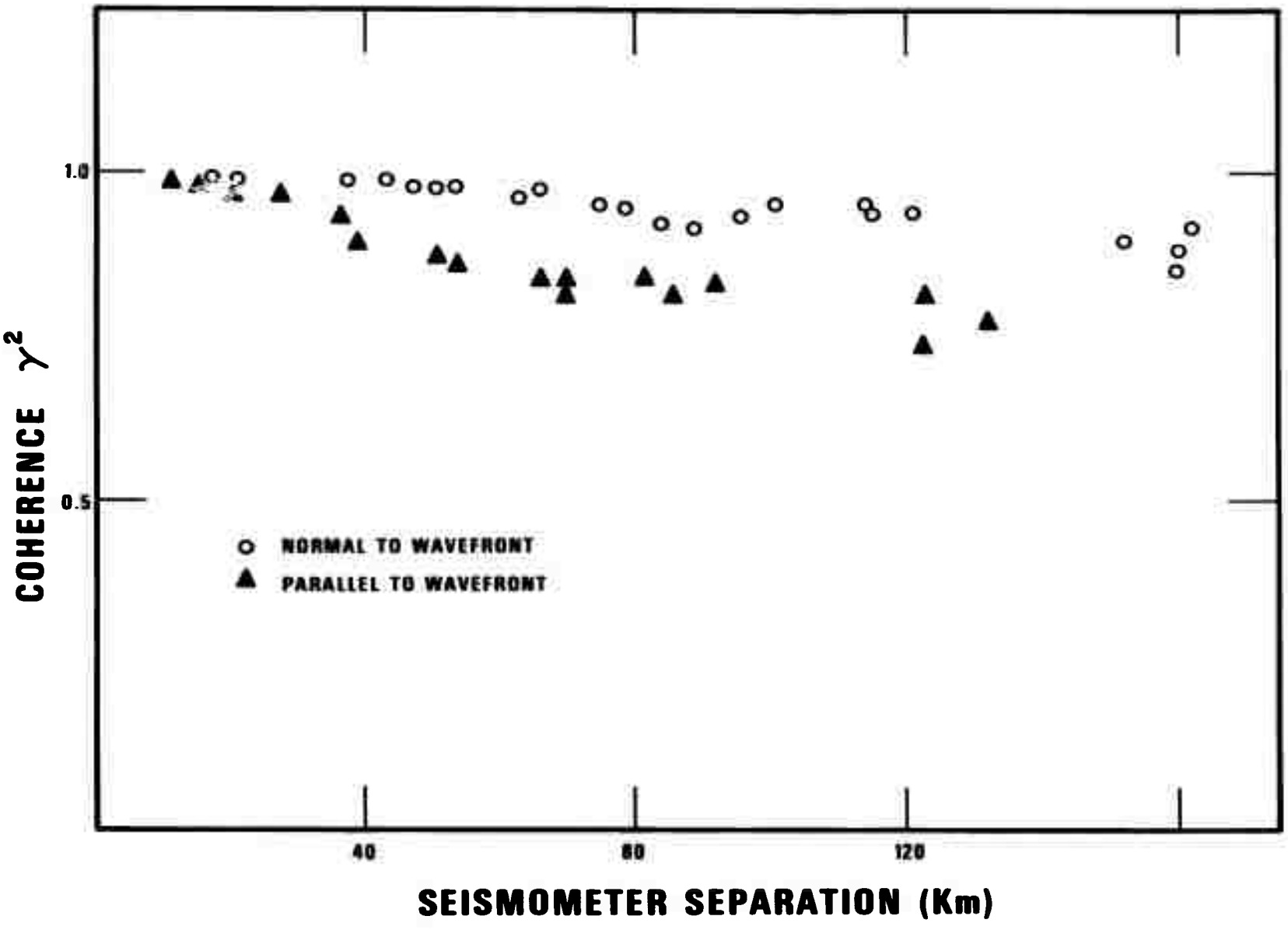

Figure 11. Spatial coherence exhibited at LASA by a Rayleigh wave from an event in Baja California.

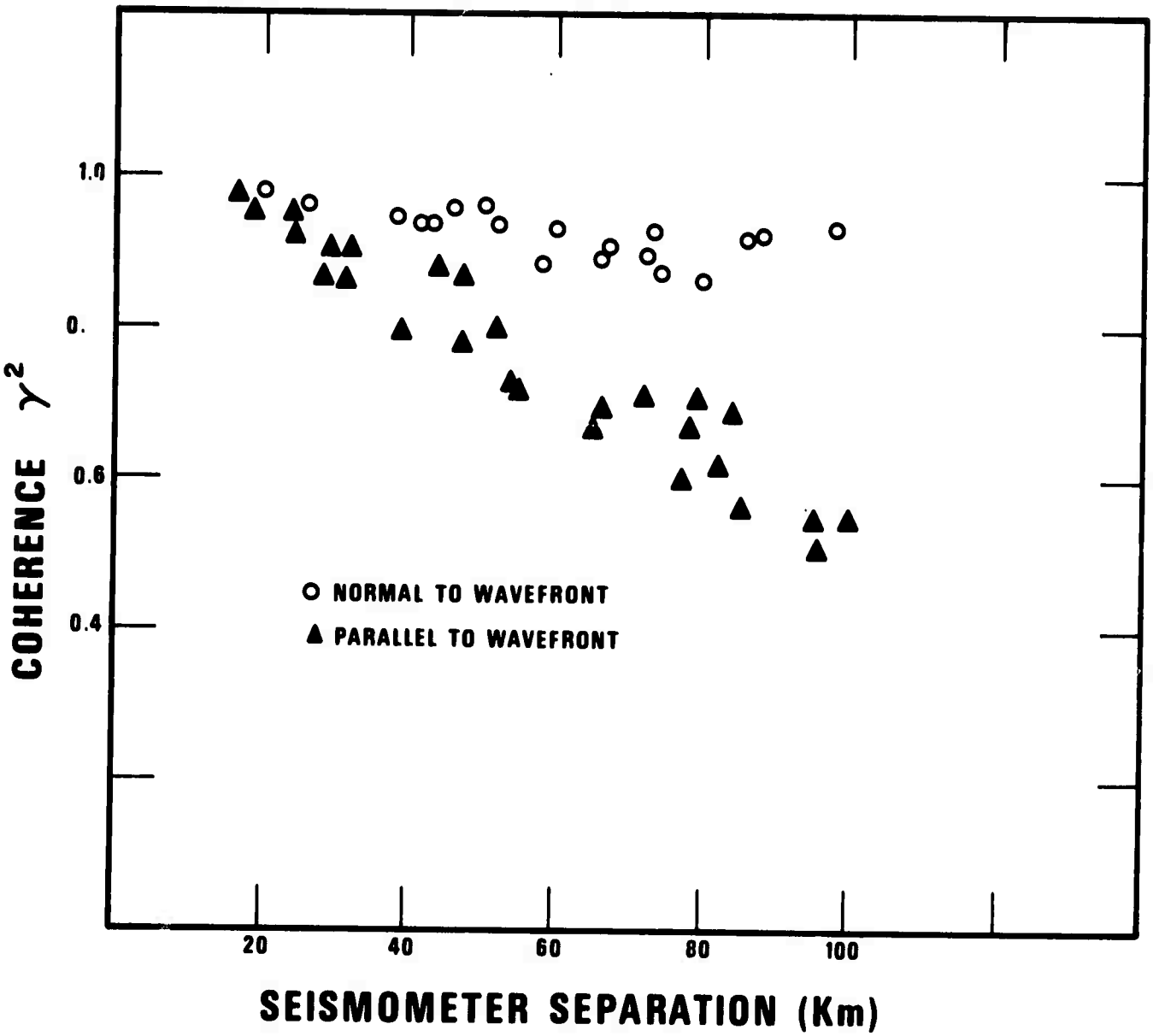

Figure 12. Spatial coherence exhibited at NORSAR by a Rayleigh wave from an event in Turkey.